TALOS: A Distributed Architecture for Intelligent Monitoring and Anomaly Diagnosis of the Hubble Space Telescope

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ABSTRACT

Lockheed, the Hubble Space Telescope Mission Operations Contractor, is currently engaged in a project to develop a distributed architecture of communicating expert systems to support vehicle operations. This architecture, named TALOS (Telemetry Analysis Logic for Operating Spacecraft) has the potential for wide applicability in spacecraft operations. The architecture mirrors the organization of the human experts within an operations control center.

The Hubble Space Telescope (HST) is presently scheduled for launch in June, 1989. When launched it will be the most complex spacecraft yet operated from Goddard Space Flight Center. Lockheed Missiles and Space Company is the prime integration contractor for the HST and is also the Mission Operations Contractor (MOC) for Goddard.

Operating the vehicle will be a knowledge intensive task. MOC personnel will be checking more than 4900 individual telemetry parameters on 200 CRT displays against a daily Mission Timeline printout several inches thick to verify spacecraft operation. Monitoring operations will continue around the clock on an almost continuous basis.

Off-line operations consist of diagnosing malfunctions and anomalies recognized by the on-line personnel, devising recovery procedures to restore normal operation once an anomaly has been understood and to track long term trends in vehicle performance. The systems engineer must be prepared to wade through a sea of data including telemetry, on-board computer memory dumps, schedule information, orbital data, and design specifications.

The MOC began to evaluate the potential of Knowledge-based software late in 1984. Interest was anything but academic. The MOC is not a research organization. If AI could help it operate the Space Telescope with greater safety and efficiency it would be used. Otherwise, effort would continue to be concentrated on conventional approaches.

The MOC's first expert system based application for the space telescope was demonstrated in the fall of 1986. The system extracted 70 different engineering parameters from a history tape recording of the vehicle engineering downlink and analyzed them with respect to vehicle safemode events. The system contained 230 rules and was able to perform in 5 or 10 minutes an analysis that would have taken a trained engineer about an hour.

This application married a telemetry extraction program written in FORTRAN with an expert system written using LES, the Lockheed Expert System. LES was a good choice for a number of reasons. First, it runs on the HST VAXes sparing the expense and difficulty of buying and integrating a LISP machine into the ground system. More importantly, LES's knowledge representation syntax is relatively straight-forward and approachable by the average spacecraft engineer. Learning to use LES is no more difficult than learning the PSTOL operating language of the HST ground system. This characteristic saves the expense and difficulty of finding or becoming LISP programmers. Finally, "customer support" for LES from the Lockheed AI center is excellent. Numerous changes have been incorporated into LES directly to support the MOC's needs.

Encouraged by the success of the first application, the MOC has, in partnership with the ST program in Sunnyvale and

the AI Center, expanded the architecture to one which has potential capabilities for automation in all our monitoring and diagnostic functions. Work has been conducted within a number of practical constraints. Development and test of TALOS cannot be allowed to place any risk or processing burdens on the existing ground system. It must be hardware and software compatible with the existing ground system. Also to be useful in the area of real-time monitoring in the STOCC it must perform very fast if it is to keep up with the incoming data. At the same time in the off-line diagnostic mode it must be flexible and offer a good explanation facility.

While LES is well suited for the off-line diagnostic role it does not have the speed to handle the quantity and rate of the HST real-time engineering downlinks. Fortunately, a symbolic processing tool several orders of magnitude faster than the current generation of expert system shells is being developed at the Lockheed AI Center. L*STAR, with it's high speed and high resolution color graphics, is an ideal tool for the on-line portions of the architecture. Like LES, L*STAR is VAX/VMS compatible and has a user-friendly knowledge representation syntax.

If there is a "classic" approach to developing an expert system it is something like this: A knowledge engineer, who knows everything about an expert system shell but nothing (initially) about the problem to be solved, "extracts" knowledge from a domain expert, who knows nothing about AI, and captures the domain knowledge in the syntax of the shell. This approach has worked well enough for small applications of 100 rules or so but it is doubtful whether it will work on a very large system. A knowledge engineer cannot build a working system if the knowledge that goes into it is unintelligible to him. He must come to understand the knowledge of the domain expert to a certain critical level to build a truly useful system. This is not a terribly tall order for a simple machine like a soup sterilizer but for the Space Telescope it is daunting.

Providing a significant level of automation in the operation of a machine as complex as the Space Telescope could easily require 10,000 rules. The expertise that would be represented in the rules lies not in a single expert but

in tens, even hundreds, of experts throughout the Space Telescope community. These experts have years of spacecraft engineering and operational experience. A further complication is that the expertise that does exist is of a particular kind. At this point experts in operating the space telescope are really experts on how it is planned to operate and how it is expected to work on orbit. Only by sifting through experience accumulated through tests and with other spacecraft can the expert come up with a sound rule for application to the HST.

It is expected to be easier to train spacecraft engineers (who, after all, are no strangers to computers and programming) how to effectively use expert system shells than to teach professional knowledge engineers how to fly the space telescope. Experience thus far has borne out this approach.

That the TALOS architecture must be a distributed one a given due to the number and over-all complexity of desired tasks. Data analysis must be shared between several expert system modules if knowledge bases are to be kept to a reasonable size. The approach in partitioning the knowledge bases has been to mirror the organization of human experts within the MOC. Modules which support on-line STOCC operations are termed "monitor modules." These modules will be active on a continuous basis and will have capabilities based on the functional responsibilities initially defined for the MOC Operations Engineering console positions. Modules which support off-line operations are, with one exception, termed "diagnostic modules." The exception is the Datamaster module which identifies and subsets telemetry or other data required by the diagnostic modules.

Since the analysis of telemetry from one subsystem is often relevant to another, TALOS modules must communicate. Monitor modules must also have the capability to send a message to a diagnostic module when an anomaly has occurred that needs to be diagnosed. Since the diagnostic modules are not active at all times, messages from the on-line modules will cause the diagnostic module to activate.

Functions supported by the monitors will be essentially identical to those performed by operations personnel, anomaly recognition, uplink management and command execution verification.

Each subsystem monitor module will recognize and provide

a warning when any vehicle operating constraint, restriction or limitation has been violated or is approaching a violation. When some immediate action should be taken in response to a malfunction the operator will be directed to the correct procedure.

Subsystem modules will generate knowledge of expected events relevant to that subsystem derived from the mission timeline. Modules will, at the time of the expected event, monitor the appropriate telemetry monitors to assure that the on-board stored commands are executing properly to accomplish the expert operation.

A special monitor system, the Operations Controller module, will check real-time commands prior to uplink to ensure that execution of the command by the spacecraft is appropriate for the current vehicle operating mode as determined through analysis of the telemetry. The Operations Controller module will also check uplink loads prior to transmission to ensure the correct load is being uplinked.

Diagnostic modules have two primary functions. First is to reduce the time required to analyze the cause of anomalies and recover from them. The second is to identify anomalous or adverse long term trends in telemetry. Diagnostic subsystem modules will be activated automatically by a monitor module when an anomaly is detected or by a human subsystem engineer. When activated automatically, a module determines what data to analyze and will attempt to diagnose the problem. Results of the analysis, either determination of a probable cause or at minimum elimination of some of the possibilities, will be printed out. Diagnostic modules will also be activated periodically to analyze archived data for anomalous or adverse trends.

Near term prospects for implementing TALOS on a large scale for the Hubble Space Telescope are uncertain due to budget and schedule constraints. Development work is expected to proceed, however. The general TALOS capabilities are applicable to almost any spacecraft operations control center. The integration of rule-based shells, telemetry data handling utilities, communications capabilities and other spacecraft related utilities that are part of the TALOS architecture can be seen as a generic system for development of highly automated spacecraft control centers.

TALOS:
EXPERT SYSTEM BASED ARCHITECTURE

SPACE TELESCOPE MISSION OPERATIONS CONTRACTOR